2011 IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA), Langkawi, Malaysia

Frictional Behaviour of Segmental Retaining Wall Units Infilled With Recycled Concrete Aggregate

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Abstract— **The use of segmental retaining wall units as the facing column for mechanically stabilized earth (MSE) retaining walls has increased noticeably all over the world. Hollow and solid, both types of modular block units are used in dry-stacked facing columns. Nowadays, Hollow concrete units are being implicated frequently because of its cost-effectiveness and other technical advantages. The cavities of hollow concrete units are filled with natural (fresh) aggregates for better shear resistance. The use of fresh aggregates as in-fillers in retaining wall constructions is expensive and unsustainable (annihilation of natural resources). This study mainly focuses on frictional behavior of newly designed and manufactured precast "I" blocks infilled with fresh and recycled aggregates. A series of tests were performed using a specially designed & fabricated direct shear apparatus to assess the frictional behavior of infilled blocks under different normal loading conditions. The tests were executed based on the exiting ASTM and National Concrete Masonry Association (NCMA) test protocols. Test results were outlined in the form of shear stress-displacement relationship to compare the effect of recycled aggregate against the fresh aggregate. Shear capacity envelopes were also plotted using Mohr-Coulomb failure criteria to find out the angle of friction for each case. Test results revealed that the angle of friction of the blocks infilled with the recycled aggregate is almost equal to those with the fresh aggregate.**

Keywords- recycled aggregate; sustainability; segmental block; interface shear; retaining wall

I. INTRODUCTION

Segmental retaining walls (SRWs) are in a period of development. They are used as the facing of mechanically stabilized earth (MSE) retaining walls in many geotechnical applications because of their sound performance, aesthetics, cost and expediency of construction. In Malaysia, the use of dry-stacked column of segmental units as a facing column in retaining wall constructions has been extensively practiced for last decades [1].

Today, facing stability is an important issue in the current design guidelines [2, 3] and it mainly depends on interface shear and connection failures. To develop interlocking mechanism between successive vertical courses of hollow units and also to increase additional shear capacity, granular infills are used in retaining wall constructions. Guler and Astarci [4] reported that granular infill (gravel) increase the angle of friction.

As granular infills, natural coarse aggregate (NCA) and recycled concrete aggregate (RCA) were used in this research to investigate its effect on the interface shear characteristics of infilled hollow units. A series of full scale laboratory tests was conducted with different types of granular infills [2, 5]. Shear stress-shear displacement graphs were drawn to compare performance of the infilled concrete units with gravels. Shear capacity envelope graphs were also plotted by using Morh-Coulomb failure criteria under peak criterion.

This reseach paper show that the use of recycled aggregate (RCA) as an infill in segmenatal retaining wall construction, has almost the equal advantages against natural coarse aggregate (NCA). It is also cost effective and environmental friendly plus giving the construction field another alternative in using in-fills for their segmental retaining walls.

II. MATERIALS

A. *Segmental Retaining Wall Unit*

In this study, locally designed and fabricated "I" blocks were used as segmental concrete units (modular block units). "I" blocks are wet cast concrete units (G30), which have one center web and the tail/rear flange is extended beyond the web (Fig. 1). The rear flange is tapered that allows the blocks to form curve walls. The maximum tapered angle of the "I" block is 11.3 deg. "I" blocks are double open-ended units and provide a larger hexagonal hollow space in conjunction with two units, and the equivalent hole dimensions are around 450 mm in length, 280 mm in width and 300 mm in height.

The infilled weight of block varies approximately 90 to 94 kg according to the unit weight of granular in-fills. The physical and mechanical properties of the used block are outlined in Table I.

B. Granular Infill

The hollow cores between the blocks were infilled with the natural coarse aggregate (NCA) and recycled concrete aggregate (RCA) and hence lightly compacted. As NCA and RCA, 100% crushed limestone aggregate and crushed concrete aggregate were used respectively. The broken and tested blocks were used as a source of recycled aggregate. They were crushed into aggregates manually using the hammer. The maximum and nominal maximum sizes of the both infilled aggregates were 25 and 19 mm respectively. The particle size distribution of the granular in-fills meets the ASTM standard size #57 gradations [6]. Fig. 2 shows the gradation curve of the used aggregates. The physical properties of the in-fillers are given in Table II.

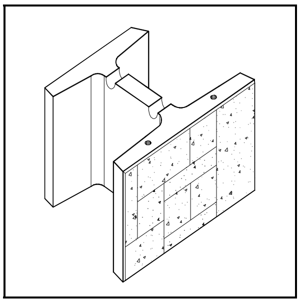

Figure 1. Schematic of the used I-Block.

TABLE I. PHYSICAL AND MECHANICAL PROPERTIES OF SEGMENTAL CONCRETE UNITS

Property		Value
Dimensions (WxHxL)[a] in mm		370x300x500
Weight (kg)		41-42
Oven dry density (kg/m^3)		2166
Water absorption capacity	%	7.1
	kg/m^3	155
Moisture content (%)		3.7
Net compressive strength (MPa)		8.0

a. W = Width (Toe to heel), H= Height, L= Length (Parallel to the wall face)

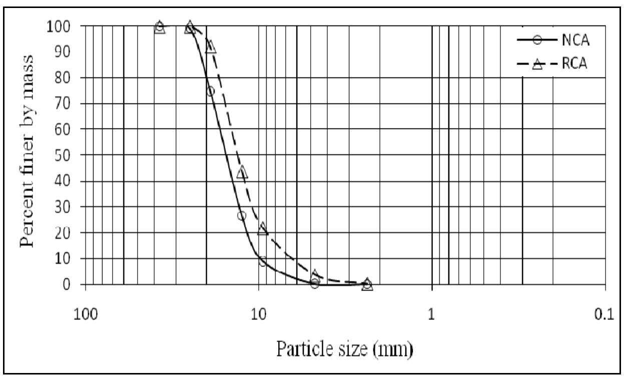

Figure 2. Grain size distribution curve for in-fillers.

TABLE II. PHYSICAL PROPERTIES OF THE INFILLERS

Property	NCA	RCA
Bulk density (Kg/m^3)	1527	1410
Specific gravity	2.63	2.42
Void content (%)	42.4	45.3
Coefficient of gradation, Cc	1.15	1.49
Fineness Modulus (FM)	7.16	6.82

III. EXPEREMENTAL PROGRAM

A. Test Apparatus

A specially designed and modified large-scale apparatus originally reported by Bathurst and Simac [7] was used to carry out the performance tests of the "I" blocks. A schematic of the modified test apparatus is illustrated in Fig. 3. It is seen that the apparatus was mainly consisting of loading frame and hydraulic actuators. The vertical actuator was mounted with the loading frame using steel rollers to allow block movement during the shear test but in ASTM [8] test protocol the vertical actuator was kept fixing. The vertical and horizontal actuators were capable of applying around 45 tons of surcharge load and 130 tons of push/pull out force respectively and simultaneously. An electric hydraulic pump was connected to the actuators with pressure hoses, and it was capable of delivering flow rate 3 cc per minute. A geosynthetic loading clamp was set with horizontal actuator to apply the tensile load as well as shear load. Two (2) pressure transducers were mounted over each hydraulic actuator of 150 mm stroke, and the actuators were calibrated by using load cell against the pressure transducers. Two (2) flow regulators were attached with the pump to control the rate of displacement of horizontal (shear) and vertical actuators.

The shear displacements were measured using of two 50 mm linear variable displacement transducers (LVDTs) with an accuracy of 0.001mm. Pressure transducers and LVDTs reading were continuously measured and recorded during the test by a data logger. The data were recorded at every 10 second interval.

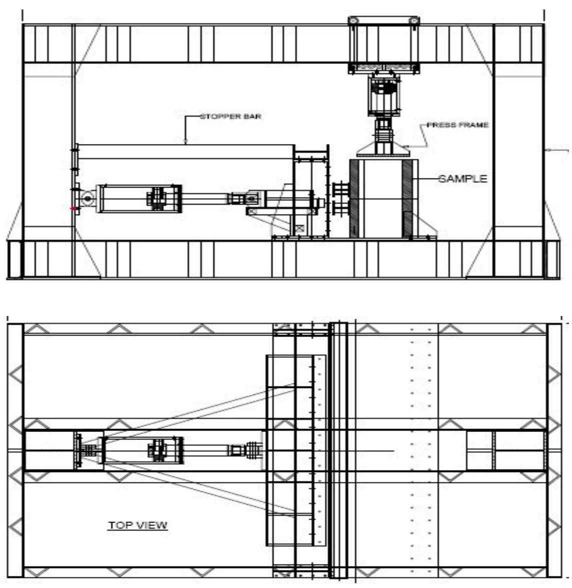

Figure 3. Schematic (side & top view) of direct shear apparatus.

B. *Interface Shear Tests*

Two layers of modular block units were used for interface shear tests. The bottom layer/course consisting of two (2) "I" blocks was installed and braced laterally at the front of loading frame. A single "I" block was placed centrally over the running joint formed by the two underlying units to simulate the staggered construction procedure used in the field. Shear pins were not used in order to lessen the number of parameter that could influence the test results. The hollow sections between the blocks were filled with 19 mm crushed stone aggregate and lightly compacted using a steel rod. To hold the infilled aggregate of top block, two (2) steel plates were used (Fig. 4).

Surcharge/normal load was imposed only over the top block through stiff rubber mat and simulated an equivalent height of stacked blocks. The shear load was applied against the top block at a constant rate of 1 mm/min [5]. A steel plate with stiff rubber mat was used with geosynthetic loading clamp to concentrate the shearing load only over the centrally installed top block. A horizontal seating load was applied to the top block to ensure close fitting of the blocks and after that the load and displacement devices were set to zero. The imposed seating load was 10% of maximum shear strength.

Mohr-Coulomb failure criteria were used to find out interface shear capacity at ultimate strength criterion.

$$V = N \tan\lambda + c. \tag{1}$$

Where:

V = Interface shear capacity (kPa)

N = Normal stress (kPa)

λ = Angle of internal friction (deg.)

c = V interception (apparent cohesion)

Figure 4. Photograph of interface shear test showing rubber mat, steel plate, and LVDTs

IV. RESULTS AND DISCUSSION

A series of interface shear tests were performed under different normal stress. Shear stress against displacement graphs were plotted to evaluate the effects of recycled aggregate on the interface frictional behavior of the "I" blocks. Shear capacity envelopes were also drawn to compare the increment of interface shear capacity because of the granular in-fills.

Figs.5 and 6 compare the purely frictional behavior of infilled concrete units under different normal stress. From the Fig.5 and 6, it is seen that the shear stress increment pattern of the infilled blocks at the initial stage is quite same for both types of aggregates but after a significant shear displacement, shear stress of RCA infilled blocks drop than those with NCA. This may be happened due to the angularity and void content of the used recycled aggregate. Recycled concrete aggregates were manually produced aggregates. By inspecting visually, it is seen that recycled concrete aggregate is more angular and also the sharp edges are relatively weaker than the fresh aggregate. Fig. 6 demonstrates the frictional behavior of RCA infilled blocks is wavier than NCA condition that results from a high normal stress, which causes stress concentration at the interface of the recycled aggregates. At high normal stress, the sharp edges of the recycled aggregates break easily that releases the interlocking among the aggregates and hence drops the shear stress for a while. Due to the relative movement of the top block, aggregates compact again and regain interlocking, finally raise the shear stress. This is continued with the mobilization of blocks.

Fig. 7 shows that the ultimate capacity of the blocks infilled with RCA is almost equal to NCA as an infill. From the Fig. 7, it is also seen that granular infill increase the interface shear capacity and it is much higher than empty condition. Granular in-fills not only increase the angle of internal friction but also increase the apparent cohesion (normal-stress independent strength) of the system (Fig. 7).This is due to the interlocking mechanism of the gravels, which enhances the positive interlock between the blocks and also increases the weight of units.

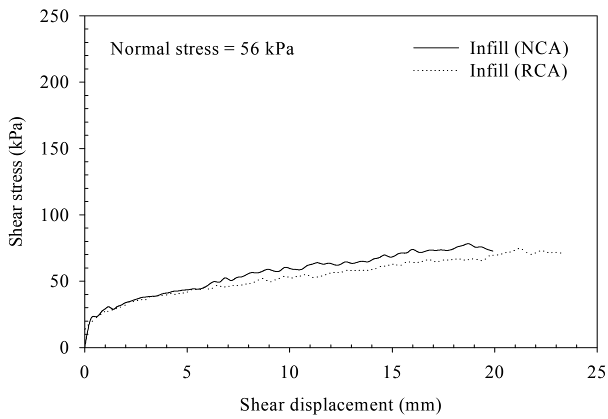

Figure 5. Shear stress against displacement

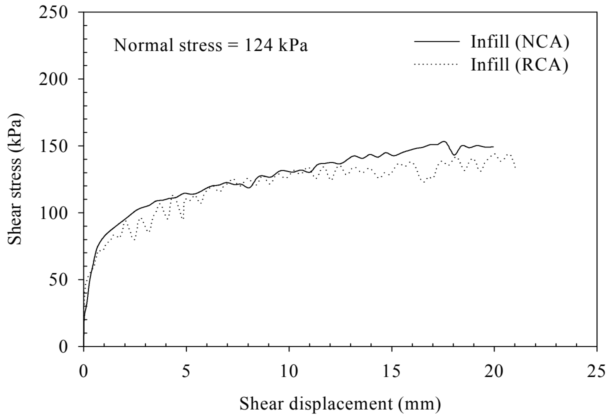

Figure 6. Shear stress against displacement

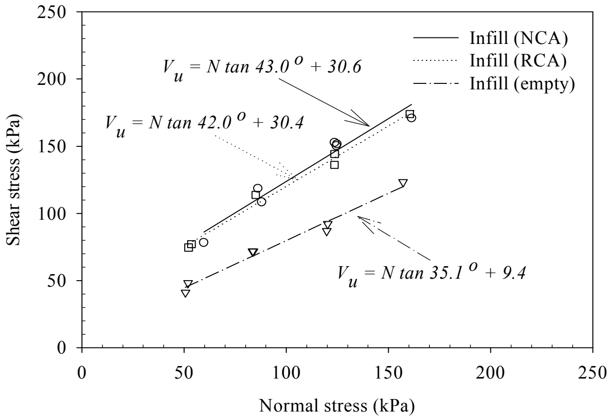

Figure 7. Ultimate shear capacity (V_u) for "I" Blocks

V. CONCLUSIONS

The results of the research indicate that the presence of aggregate increases the interface shear capacity of the "I" block system. Ultimate frictional capacity of the blocks infilled with the recycled concrete aggregate (RCA) is almost equal to that of natural coarse aggregate (NCA).

ACKNOWLEDGMENTS

The authors would like to thank Mr. Siau Lian Sang, Managing Director of Soil & Slope Sdn Bhd in Malaysia, who provided materials and technical support to carry out the experiment work. Finally, the authors wish to acknowledge the funding (Fundamental Research Grant Scheme- 2010) provided by the Ministry of Higher Education (Malaysia) awarded to the University of Malaya.

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